

Did the progenitor of SN 2011dh have a binary companion? *

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ABSTRACT

We present late-time Hubble Space Telescope (HST) ultraviolet (UV) and optical observations of the site of SN 2011dh in the galaxy M51, ~ 1164 days post-explosion. At the SN location, we observe a point source that is visible at all wavelengths, that is significantly fainter than the spectral energy distribution (SED) of the Yellow Supergiant progenitor observed prior to explosion. The previously reported photometry of the progenitor is, therefore, completely unaffected by any sources that may persist at the SN location after explosion. In comparison with the previously reported late-time photometric evolution of SN 2011dh, we find that the light curve has plateaued at all wavelengths. The SED of the late-time source is clearly inconsistent with a SED of stellar origin. Although the SED is bright at UV wavelengths, there is no strong evidence that the late-time luminosity originates solely from a stellar source corresponding to the binary companion, although a partial contribution to the observed UV flux from a companion star can not be ruled out.

Key words: supernovae:general – supernovae:individual (2011dh)

1 INTRODUCTION

Most massive stars with $M_{\text{ZAMS}} > 8M_{\odot}$ are expected to end their lives as core-collapse supernovae (SNe) (Smartt 2009). While there has been major success in the direct identification of the red supergiant progenitors of the H-rich Type IIP SNe, attempts to identify the progenitors of the H-deficient Type Ibc SNe have been less conclusive (Eldridge et al. 2013). There are predicted to be two distinct progenitor channels for these SNe: extremely massive stars ($> 30 - 40M_{\odot}$) which lose their hydrogen envelopes through intense stellar winds, and lower mass stars undergoing a binary interaction. Eldridge et al. (2013) showed that, given the available pre-explosion detection limits for nearby Type Ibc SNe, the underlying population of progenitors was required to come from a mixture of the two progenitor channels. Evidence from the sole detection of

the progenitor of a Type Ib SN, iPTF 13bvn, suggests that a lower mass binary progenitor may be responsible, rather than a single massive star (Cao et al. 2013; Groh et al. 2013a; Fremling et al. 2014; Bersten et al. 2014; Eldridge et al. 2015).

SNe of Type IIb initially display hydrogen in their early spectra; however, with time these H features grow weaker until the SN transitions to a H-deficient Type Ib SN. Type IIb SNe may, therefore, be considered “transition” SNe connecting the H-rich and H-poor SNe (Filippenko et al. 1993; Filippenko 1997). It is thought that the progenitors of Type IIb SNe have been stripped of all but $\sim 0.1M_{\odot}$ of their H envelope (Smith 2014), highlighting the importance of mass loss, either through winds or binary interaction to the origin of the subtypes in the SN classification scheme (Nomoto et al. 1996). Unlike their completely H-deficient cousins, however, there has been significant success in the identification of the progenitors stars of Type IIb SNe in pre-explosion observations (Aldering et al. 1994; Crockett et al. 2008; Maund et al. 2011; Van Dyk et al. 2011, 2014).

The small amount of residual hydrogen on the progenitor means that the degree of mass loss prior to explosion required to

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reproduce both the progenitor and SN characteristics must be very finely tuned in theoretical models. This makes the progenitors of Type IIb SNe exquisite probes of stellar mass loss through both binary interactions and winds. As demonstrated by Maund & Smartt (2009), late-time observations of the sites of SNe, for which the progenitors have been identified in fortuitous pre-explosion images, allows for an enhanced analysis of the progenitor by studying what is left over after the explosion. This approach permits confirmation of the original identification of the progenitor candidate (through it's disappearance), the search for any remaining stellar components (a binary companion) and enhanced photometric accuracy (through the use of image subtraction techniques). Here, using late-time Hubble Space Telescope (HST) observations, we apply these techniques to the study of the progenitor of SN 2011dh.

SN 2011dh was discovered on 2011 May 31 in the galaxy M51 (Arcavi et al. 2011). A yellow stellar source was detected at the SN location in pre-explosion HST images, and interpreted as a supergiant by Maund et al. (2011) and Van Dyk et al. (2011). The SN exhibited rapid temperature evolution, however, during the shock cooling phase (Arcavi et al. 2011) which indicated the possible explosion of a compact progenitor rather than an extended supergiant. Late-time observations by Van Dyk et al. (2013a) demonstrated the disappearance of the yellow source in late-time observations, confirming the conclusion of Maund et al. that the progenitor of SN 2011dh was a Yellow Supergiant (YSG). Theoretical models by Bersten et al. (2012) and later Nakar & Piro (2014) were able to reconcile the SN shock cooling behaviour with the extended progenitor observations, concluding that the progenitor had a compact core with a very low-mass extended H-envelope. In keeping with the study of Maund et al., we adopt a distance to M51 of 7.1 ± 1.2 Mpc distance to M51 (Takáts & Vinkó 2006) and a foreground reddening of $E(B - V) = 0.032$ (Schlafly & Finkbeiner 2011).

2 OBSERVATIONS

Details of the pre-explosion and late-time HST observations of the site of SN 2011dh are presented in Table 1. The late-time WFC3/UVIS and ACS/WFC observations were acquired 1164 and 1167 days post-explosion, respectively (Ergon et al. 2014b). The pre-explosion observations of the site of SN 2011dh were acquired with the HST Advanced Camera for Surveys (ACS) Wide Field Channel (WFC) and Wide Field Planetary Camera 2 (WFPC2). Details of the pre-explosion HST observations used here (and their reduction and analysis) are presented by Maund et al. (2011). The late-time observations of the site of SN 2011dh were conducted in the optical/near-infrared with the ACS/WFC and in the ultraviolet with the Wide Field Camera 3 (WFC3) Ultraviolet and Visible Channel (UVIS), as part of programme GO-13433 (PI Maund) shared with programme GO-13345 (PI Arcavi). The filters utilised for the late-time observations were specifically selected to match the filters of the available pre-explosion observations as closely as possible. The late-time observations for each filter, with both instruments, were acquired using a sequence of four dithered exposures, permitting the rejection of cosmic rays and hot pixels and also providing finer sampling of the point spread function (PSF). The dithered exposures were combined using the *astrodrizzle* package, running under PyRAF¹, with final pixel scales of $0.02 \text{ arcsec px}^{-1}$

for the WFC3/UVIS observations and $0.025 \text{ arcsec px}^{-1}$ for the ACS/WFC observations. Photometry of the late-time observations was conducted using DOLPHOT² (Dolphin 2000) with the specific ACS and WFC3 modules.

The position of SN 2011dh on the late-time *F555W* image was determined with respect to the pre-explosion source, previously identified by Maund et al. (2011) in the pre-explosion *F555W* image, to within $0.016''$ ($N = 23$). The position of the SN on the late-time WFC3/UVIS *F336W* image was determined using a geometric transformation calculated between that image and the late-time ACS/WFC *F555W* image, to within an uncertainty of $0.018''$ ($N = 20$). The PyRAF task *crosscor* was used to refine offset in the registration between the late-time observations that were, nominally, acquired at the same pointing.

3 RESULTS & ANALYSIS

A selection of the pre-explosion and late-time observations of the site of SN 2011dh are presented in Figure 1. In all the late-time observations, from the ultraviolet to the near-infrared, a source is clearly recovered at the SN position. The late-time source is clearly resolved from nearby sources and DOLPHOT PSF-fitting photometry reported the shape of the source (evaluated using the sharpness and χ^2 values) to be consistent with a single point source in all bands. Photometry of the late-time source, in comparison with the pre-explosion observations, is presented in Table 2. The photometry of the late-time source shows that it is significantly fainter than the pre-explosion in all of the shared photometric bands (see Fig. 2); confirming the previous observations of Van Dyk et al. (2013b) and Ergon et al. (2014b) that the YSG observed at the SN position prior to explosion is no longer present and, hence, was the progenitor. The relative faintness of the late-time source also implies that any remaining component of the progenitor system (i.e. a binary companion) was not a major contributor to the brightness of the pre-explosion source, in particular in the *F336W* band (where the late-time flux is lower than the observed pre-explosion flux by a factor of ~ 4). This implies that the analysis of the pre-explosion observation of the YSG progenitor, presented by Maund et al. (2011), is still valid: $\log(L/L_{\odot}) = 4.92 \pm 0.20$, $T_{\text{eff}} = 6000 \pm 280\text{K}$ and subject to $E(B - V) = 0 - 0.032$ mags. In all the late-time observations we see no evidence for spatially resolved light echoes in the vicinity of SN 2011dh, which is consistent with the low degree of reddening reported to SN 2011dh itself.

Utilising our own SED fitting code, we attempted to fit the SED of the late-time source with ATLAS 9 model SEDs (Castelli & Kurucz 2004) for single supergiant stars. Using the reddening reported for SN 2011dh as a prior, the most likely solution yielded $\chi^2 = 92.4$, implying that the SED of the late-time source is inconsistent with a stellar source. Given the late-time photometric evolution of SN 2011dh reported up to $\sim 350\text{d}$ by Shivvers et al. (2013) and $\sim 700\text{d}$ by Ergon et al. (2014a), the shape of the SED suggests a significant contribution from the still bright SN. Using the late-time photometric observations reported by Ergon et al. (2014a), with HST photometry from 2013 (Van Dyk et al. 2013b), we find that the behaviour of SN 2011dh at epochs prior to our HST observations were inconsistent with a linear decay and are, rather, better approximated by a power law (of the form $m = \alpha t^{\beta}$; see Fig.

¹ STSDAS and PyRAF are products of the Space Telescope Science Institute, which is operated by AURA for NASA

² <http://americano.dolphinsim.com/dolphot/>

Table 1. Pre-explosion and late-time HST observations of the site of SN 2011dh in M51

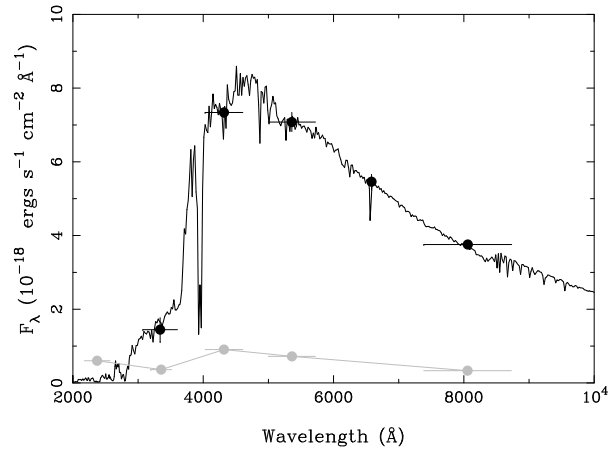
Date (UT)	Filter	Instrument	Exposure Time(s)	Pixel Scale arcsec	Program
Pre-explosion					
21 Jan 2005	<i>F435W</i>	ACS/WFC	2720	0.025	10452 ¹
21 Jan 2005	<i>F555W</i>	ACS/WFC	1360	0.025	10452
21 Jan 2005	<i>F658N</i>	ACS/WFC	2720	0.025	10452
21 Jan 2005	<i>F814W</i>	ACS/WFC	1360	0.025	10452
13 Nov 2005	<i>F336W</i>	WFPC2/WF2	2600	0.1	10501 ²
Late-time					
07 Aug 2014	<i>F225W</i>	WFC3/UVIS	3772	0.02	13433 ³
07 Aug 2014	<i>F336W</i>	WFC3/UVIS	1784	0.02	13433
10 Aug 2014	<i>F435W</i>	ACS/WFC	1072	0.025	13433
10 Aug 2014	<i>F555W</i>	ACS/WFC	1232	0.025	13433
10 Aug 2014	<i>F814W</i>	ACS/WFC	2176	0.025	13433

¹ PI: S. Beckwith, ² PI: R. Chandar, ³ PI: J. Maund**Table 2.** Photometry of the sources at the position of SN 2011dh in pre-explosion and late-time HST observations

Filter	Pre-explosion (mags)	Late-time (mags)
<i>F225W</i>	...	24.61(0.11)
<i>F336W</i>	23.39(0.25)	24.89(0.11)
<i>F435W</i>	22.36(0.02)	24.63(0.04)
<i>F555W</i>	21.83(0.04)	24.31(0.03)
<i>F658N</i>	21.28(0.04)	...
<i>F814W</i>	21.20(0.03)	23.83(0.02)

3). The most recent late-time HST photometric measurements reported here are, however, even inconsistent with these earlier light curve trends and Figure 3 shows that the light curve has flattened across all wavelengths.

In light of the still significant late-time contribution of the SN at optical wavelengths, it is difficult to place specific constraints on the presence of a binary companion that also contributes to the late-time SED. Under the assumption that the SN component is weakest in the UV, while a companion star's SED might peak in UV, we may attempt to place constraints on the allowed parameters for the companion given these observations. We consider two scenarios for the origin of the late-time UV flux: 1) all of the observed *F225W* and *F336W* flux arises from a companion star; and 2) all of the *F225W* flux and a portion of the *F336W* flux arises from a companion. Given these assumptions, the corresponding permitted regions for the companion star on the Hertzsprung-Russell diagram (HRD) are presented on Fig. 4. For the second scenario, we utilised the ACS/WFC *F435W* photometry as a further constraint on the temperature, as stars cooler than $T \sim 10\,000\text{K}$ would be brighter than the observed SED at that wavelength. Under the first assumption, due to correlations between luminosity and temperature, all of the Benvenuto et al. (2013) models for the companions, covering a range of mass accretion efficiencies, fit the observed UV photometry. Under the second assumption, only the binary companion models with the smallest mass accretion efficiencies ($\beta \leq 0.25$) or main sequence companions with $M \leq 13M_{\odot}$ are allowed.

**Figure 2.** The observed SED of the pre-explosion (heavy points) and late-time (light points) sources at the position of SN 2011dh. Overlaid is a Castelli & Kurucz (2004) ATLAS9 synthetic spectrum ($T_{\text{eff}} = 6000\text{K}$) appropriate for the best fit solution for the pre-explosion photometry derived by Maund et al. (2011).

4 DISCUSSION AND CONCLUSIONS

Previously, using the subset of late-time *F225W* and *F336W* observations presented here, Folatelli et al. (2014) claimed the detection of a hot, compact companion as predicted by Benvenuto et al. (2013). In the course of their analysis, however, Folatelli et al. had to make the key assumption that the UV flux *only* originated from the binary companion, and then were only able to constrain the properties using two photometric data points. A fundamental test of this hypothesis would be the decreasing flux at redder wavelengths, which is clearly at odds with the observed non-stellar optical SED (see Fig. 5). The late-time brightness of SN 2011dh at optical wavelengths is unexpected given the late-time evolution reported by Shivvers et al. (2013) and Ergon et al. (2014a), but also raises serious concerns about the degree of the SN contribution at UV wavelengths, specifically where Folatelli et al. have claimed to observe the binary companion.

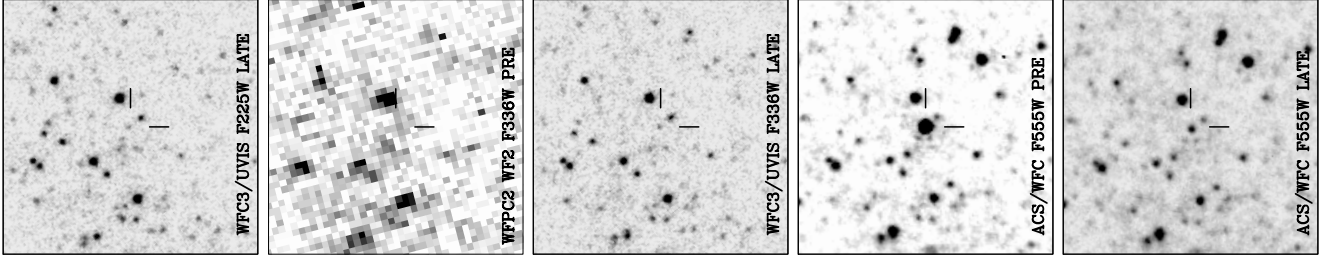


Figure 1. The site of SN 2011dh observed prior to explosion and at late-times with HST. Each image panel is centred on the SN position (indicated by the cross hairs), with dimensions $4\text{arcsec} \times 4\text{arcsec}$ and is oriented such that North is up and East is to the left. The panels are, from left to right: Late-time WFC3/UVIS $F225W$ observation; Pre-explosion WFC2/WF2 $F336W$ observation; Late-time WFC3/UVIS $F336W$ observation; Pre-explosion ACS/WFC $F555W$ observation; and late-time ACS/WFC $F555W$ observation.

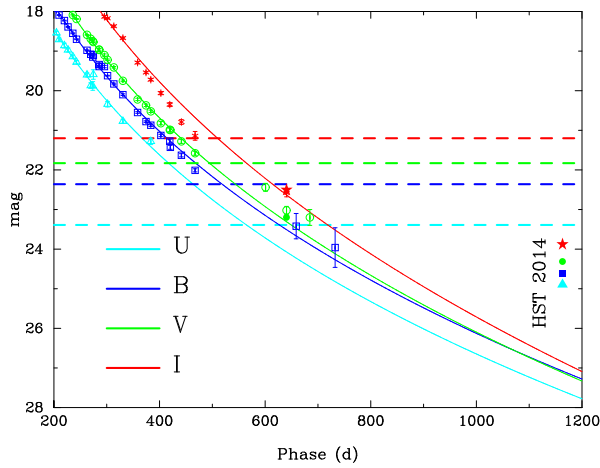


Figure 3. Late-time photometry of SN 2011dh from Ergon et al. (2014a) and HST (from 2013 and 2014; solid symbols). Solid lines indicate the power law fits to ground based and HST observations prior to our 2014 observations. Horizontal dashed lines indicate the brightness of the progenitor in the pre-explosion observations.

Ergon et al. (2014a) discuss the late time evolution of SN 2011dh and find that the radioactive energy deposition is likely insufficient to reproduce the late time (600-750 days) optical luminosity. "Freeze-out" in the helium envelope could also be a possible additional energy source. Ergon et al. (2014a) also report strong flattening of the observed mid-infrared (MIR) lightcurve after 750 days. If we use the optical decline rate before 750 days and the MIR decline rate thereafter, we find a drop of 1.0 mag between 640 and 1166 days, which is in good agreement with the observed drop of 1.1-1.2 mag in the late-time (2014) $F555W$ and $F814W$ photometry and suggests that the flattening of the light curve is relatively wavelength independent (see Fig. 3).

In Fig. 5 we show the SEDs for the steady-state non-Local Thermodynamic Equilibrium models 12C and 12B of Jerkstrand et al. (2015) at 500 days, who provide examples of how the SED of the SN would look in the radioactively powered scenario. These models only differ in the treatment of positron trapping (local or non-local), and are able to reproduce the lightcurve (Ergon et al. 2014a) and spectra (Jerkstrand et al. 2015) of SN 2011dh over the period of 100-500 days. We also show the observed SED of SN 1993J at 674 days (Van Dyk et al. 2002), which provides an example of how the SED would look like if there was a contribution from the strong interaction of the ejecta with the circumstellar

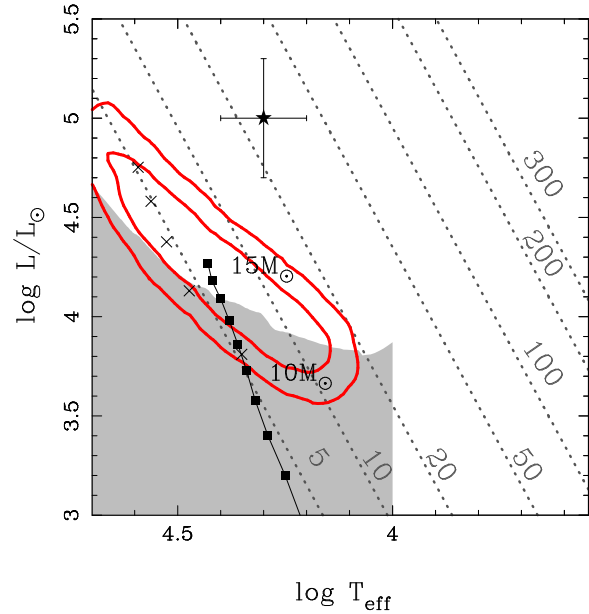


Figure 4. Hertzsprung-Russell diagram showing the permitted locations for a possible binary companion, given the late-time photometry, under the assumptions: 1) all UV flux arises from the companion (red contours) and 2) only the $F225W$ flux arises from the companion (grey shaded region). The upper limit of the grey shaded region corresponds to position on the HRD where the probability of detection of such a star is 50%. The starred point corresponds to the position of the companion star identified for the progenitor of Type IIb SN 1993J (Maund et al. 2004). The positions of possible binary companions predicted by Benvenuto et al. (2013) are indicated by the crosses (\times) and the main sequence for stars with $M_{ZAMS} \leq 15M_{\odot}$, for integer masses from the STARS stellar evolution code (Eldridge & Tout 2004), are shown by the filled squares (\blacksquare). The dotted lines indicate lines of constant radius (as labelled in solar radii).

medium (CSM). As seen in Fig. 5, the shape of the observed SED in the optical is consistent with what could be expected for the SN in the radioactively powered scenario, but does not explain the UV portion of the SED (and could, possibly, require a binary companion). This requires, however, that there is no contribution due to the any late interaction with the CSM and that the $F225W$ - $F336W$ colour for the freeze-out powered scenario is not considerably bluer than for the radioactively powered scenario. As discussed in Ergon et al. (2014a), there are no clear signs of significant CSM interaction in the spectrum of SN 2011dh acquired at 678 days presented by Shivvers et al. (2013), which disfavours the CSM powered sce-

nario. While an investigation of how the SED would look in the freeze-out powered scenario is outside the scope of this paper, at this point we can not rule out that the observed flux in the F225W filter, and any of the other filters, originates solely from the SN. If the optical flux is dominated by the SN at 1164 days, the radioactively powered scenario can be ruled out, as the optical luminosity alone would then be 1.9 mag higher than the bolometric luminosity in models 12C and 12B.

To consider the role of CSM interaction in the behaviour of the late-time lightcurve of SN 2011dh, we obtained target-of-opportunity X-ray observations at the position of SN 2011dh with the X-ray telescope (XRT Gehrels et al. 2004) on-board the *Swift* Gamma-Ray Burst Explorer (Gehrels et al. 2004) on 2014 Sep 17 (4.9 ks) and 2014 Sep 24 (4.9 ks). While generally following standard algorithm for automated analysis of XRT data (e.g., Evans et al. 2009), we manually selected background regions due to the complex nature of diffuse and/or unresolved emission from M51³. We find no evidence for significant point source emission (i.e., above and beyond the underlying background) at the position of SN 2011dh, down to a 3σ limit of $2 \times 10^{-13} \text{ erg s}^{-1} \text{ cm}^{-2}$, which corresponds to a luminosity of $\sim 1.22 \times 10^{-39} \text{ erg s}^{-1}$.

We also obtained late time radio observations of SN 2011dh with the Jansky Very Large Array (VLA). The observations were performed on October 18, 2014 UT at central frequencies of 6.1 GHz (C-band) and 22 GHz (K-band) using 3C286 as a flux calibrator and J1349+5341 as phase calibrator. We detect weak radio emission from the SN at flux levels of $459 \pm 93 \mu\text{Jy}$ and $109 \pm 17 \mu\text{Jy}$ at C-band and K-band, respectively. Past radio observations, from day ~ 4 until day ~ 90 after explosion, have already shown radio emission thus indicating interaction of the SN ejecta with CSM (Krauss et al. 2012; Soderberg et al. 2012; Horesh et al. 2013). Our late time radio measurements are well within the expectations based on the earlier measurements, assuming that the CSM has an extended wind-like structure. The lack of excess in radio emission thus suggests that there is no additional interaction with an enhanced CSM.

While the X-ray and radio observations rule out strong ongoing CSM interaction at the time of the late-time HST observations, portions of the UV and optical SED could be enhanced by emission lines generated in some low level interaction. Lines such as C II $\lambda\lambda 2324, 2325$ and [Ne III] $\lambda\lambda 3868, 3869$ (Fesen et al. 1999) could contribute flux to the observed F225W and F336W photometry. Ultimately a UV late-time spectrum of SN 2011dh, which is unfortunately unfeasible with HST, would be required to establish if such emission lines are present, without a commensurate signal for CSM interaction in the X-ray and radio regimes. While earlier CSM interaction is ruled out by the spectra presented by Shivers et al. (2013), without similar spectra at epochs comparable to our late-time HST observations it is difficult to assess whether any interaction might have started in the intervening period between those observations and our 2014 observations when the light curve appears to have flattened (which could mark a period of earlier enhanced mass loss in the history of the progenitor).

Alternatively, the late-time flux could arise from early SN flux scattered into the line of sight by dust, forming a light echo (Rest et al. 2011). We note, however, that in all the late-time observations SN 2011dh appears point-like, which would require the scattering dust to have a very specific arrangement, lying behind the SN and

exactly along the line of sight, which would be unlikely to occur by chance. In addition, given the low reddening estimated towards SN 2011dh there is no evidence for large amounts of dust in the SN locality. We therefore discount the possibility of a light echo being the origin of the observed late-time brightness of SN 2011dh.

Based on the late-time HST observations presented here, there is, as yet, no conclusive evidence for the recovery of a binary companion associated with SN 2011dh. The presence of significant late-time flux at optical wavelengths for SN 2011dh suggests that the origin of the UV flux is highly uncertain and not necessarily attributable to a binary companion. HST observations of SN 2008ax at a similar epoch in its evolution (Maud et al., in prep.), exhibited a similar rise at UV wavelengths (see Fig. 5), however there is no comparable observation with shorter wavelength filter to confirm that this rise in the SED continues in the UV as observed for SN 2011dh. In the case of SN 2008ax, even later HST observations confirmed the disappearance of the progenitor star, with no stellar residual at the SN location, corresponding to a binary companion, at UV or optical wavelengths. Alternatively, given the late-time brightness of SN 2011dh, a binary companion could be still be "hidden" by the SN, in which case its luminosity and, hence, mass would be lower than the optimistic interpretation of the UV observations presented by Folatelli et al. (2014) and its role in the evolution of the progenitor might be diminished. Constraining the progenitor to a lower mass has important implications for interacting binary evolution models. A lower mass would indicate that the mass transfer responsible for removing the hydrogen envelope was less efficient than for the case of SN 1993J, with most of the mass lost from the binary system rather than ending up in the companion star. Later, deeper observations once SN 2011dh has faded even more may permit the detection of a lower mass binary companion if it is present.

A fundamental question raised by these observations, however, is whether a binary companion is a prerequisite for the final appearance of the progenitor of SN 2011dh. There is significant evidence for the presence of a hot binary companion to the progenitor of SN 1993J (Aldering et al. 1994; Maud et al. 2004; Fox et al. 2014), the class prototype of Type IIb SNe. Georgy (2012), however, found that it was possible to produce YSG progenitors through single star evolution through the inclusion of rotation and by enhancing the mass loss for a $M_{\text{ZAMS}} = 15M_{\odot}$ star by a factor of 10. This enhanced mass loss rate is, however, consistent with the observed levels of mass loss for some Red Supergiants (van Loon et al. 2005) and given the measured luminosity of the progenitor of SN 2011dh the expected mass loss rate of $\sim 10^{-5} M_{\odot} \text{ yr}^{-1}$ (Georgy et al. 2012) is consistent with the mass loss rate inferred from radio observations of the SN itself (Soderberg et al. 2012). In isolation, for a rotating $M_{\text{ZAMS}} = 18M_{\odot}$ star, Groh et al. (2013b) found the progenitor evolved to become a YSG, instead of exploding as a Red Supergiant. This may suggest that new mass loss rate prescriptions and rotation may make YSGs the natural endpoint for some stars of mass $\sim 13M_{\odot}$, such as the progenitor of SN 2011dh. It should be noted that the mass-loss rates of RSGs are poorly known; even for stars of similar luminosities mass-loss rate determinations from the literature (van Loon et al. 2005; Mauron & Josselin 2011) vary over several orders of magnitudes. The reason for the scatter is unclear, which could be due to unseen companions, eruptive episodes of mass loss or a yet to be identified physical process, but could lead to stars of similar initial mass evolving very differently towards the ends of their lives.

While mass transfer in binary systems can be invoked to explain the observed properties of H-poor YSG progenitors, there is

³ Note that we verified that this diffuse component is unrelated to SN 2011dh by examining *Swift*-XRT observations of the field from 2005.

a significant increase in the parameter space in which acceptable models might arise. From the perspective of stellar evolution models, in both the single and binary scenarios, predicting the final temperature of a YSG progenitor requires fine tuning the adopted mass loss rate. The case of the progenitor of SN 2011dh may serve to highlight the importance of understanding gaps in our knowledge of single star evolution and of how the light curves of SNe at late-times are powered.

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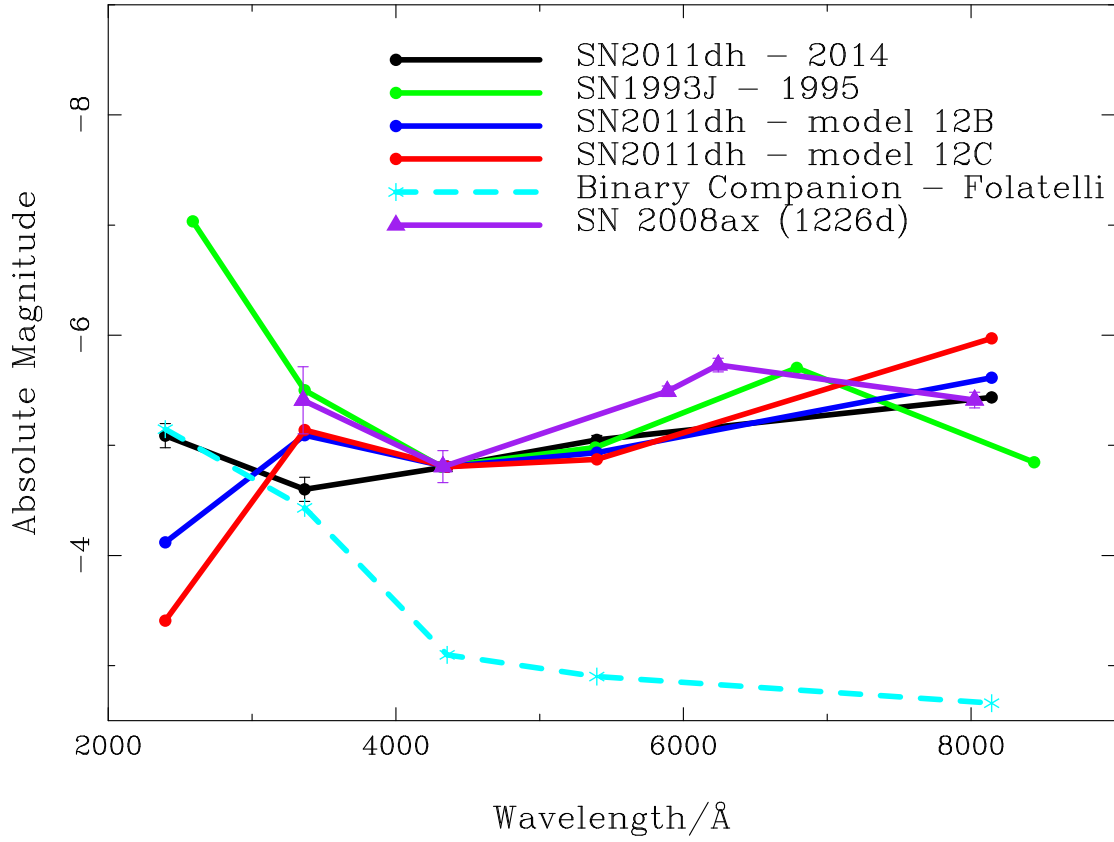


Figure 5. Theoretical and observed late-time SEDs, in units of absolute Vega magnitudes, for Type IIb SNe compared to the observed late-time SED of SN 2011dh. The SEDs are normalised to the brightness of the late-time source recovered at the position of SN 2011dh, as observed in the ACS/WFC *F435W* band. Also overlaid are the SED of the binary companion proposed by Folatelli et al. (2014) and the observed SED of SN 2008ax at 1226d (corrected for $E(B - V) = 0.4$; Maund et al., 2015).